MONITORING FOR WATER QUALITY OBJECTIVES IN RESPONSE TO NONPOINT SOURCE POLLUTION

K. W. THOMSON
Water Quality Branch
Environment Canada
Regina, Saskatchewan

G. D. HAFFNER
Water Quality Branch
Environment Canada
Ottawa, Ontario

ABSTRACT

The broad application and continued use of herbicides and pesticides have resulted in a major diffuse source input of toxic material into aquatic ecosystems. The most common present water quality assessment practices cannot account for the entry of such compounds into the environment. Unlike point source input, where levels, quantity, and consistency of loadings are known, diffuse source input must be estimated using assessment procedures. Consequently, these assessment practices are not designed for the development or site-adaptation of water quality objectives—in Canada, water quality objectives are used for determining best land use practice and providing protection to the aquatic ecosystem. These demands on environmental assessments and the subsequent development of relevant water quality objectives can only be achieved by studies that provide insight into aquatic system behavior. The different environment processes and fates that potentially regulate a compound's effect in the aquatic ecosystem emphasize the need for system behavior information. Examples from different systems illustrate the need for more comprehensive water quality assessment procedures to develop water quality objectives relevant to diffuse source inputs.

INTRODUCTION

Management of water quality within an aquatic ecosystem involves three facets: measurement, evaluation, and remedial action. Measurement pertains to the collection of physical, biological, and chemical water quality data. Evaluation necessitates a set of criteria with which the measured water quality can be realistically compared (in Canada these criteria take the form of water quality objectives—negotiated limits designed to protect and support designated water uses). These objectives provide the link between water quality information and the water uses to be protected and maintained within a given waterbody. Remedial actions, if required for use protection, are based on the measurement and evaluation information.

Approaches to the monitoring and assessment of water quality, as well as water quality management, will vary according to the relative significance of nonpoint and point source pollution. Specific water quality objectives that are used for evaluation do not vary similarly; however, their effectiveness depends upon the related data as well as the resultant management responses to them. Although water quality objectives have application for both nonpoint and point source pollution, the development of these objectives, their monitoring requirements, and the appropriate management strategies may differ significantly. The remainder of this discussion focuses on monitoring approaches, with regard to water quality objectives, and the assessment of nonpoint source pollution.

Point source inputs to an aquatic ecosystem are usually a consistent load of a given set of materials or chemicals. Data sets can be generated in specific areas of a river basin, and areas of noncompliance established with remedial actions confined to specific sources. Diffuse loadings from land use or atmospheric inputs tend to be more event oriented without a quantifiable area of effect in the aquatic environment. Basically, the complex nature of diffuse-source inputs results in the need for more comprehensive and extensive measurements and evaluation for development of a suitable management strategy.

Nonpoint source pollution in Canada most often results from agricultural practices, urban runoff, and atmospheric deposition. Aspects of these concerns are contained in three highly interrelated departmental priorities recently identified by Environment Canada: Toxic Chemicals, Long Range Transport of Airborne Pollutants, and Water Management (Environ. Can. 1983). To address these priorities, data must be assembled, an evaluatory mechanism initiated, and response programs implemented. Data collection necessitates an effective monitoring program; evaluation may correspond to the use of water quality objectives and the response usually consists of developing and implementing management options.

This discussion critically examines the measurements and evaluations required to develop water quality objectives specifically for nonpoint source inputs. Selected examples illustrate how such measurement might be used to determine the need and type of remedial action required to protect the aquatic environment.

MONITORING NONPOINT SOURCE POLLUTION

Water quality management requires a multiplicity of data to resolve the conflict of economic uses (industrial, agricultural) of water and the health of the aquatic environment (drinking water, fisheries, recreation). Historically, monitoring programs have been expected to yield information on many different aspects of water quality, and as a result data bases were established with many distinct and often incompatible rationales and designs. Generally, however, these measurement rationales and designs can be described in one of the following categories of environmental monitoring: (1) crisis response, (2) general monitoring, and (3) understanding aquatic processes.

Crisis Monitoring

Crisis monitoring, the oldest form of environmental data collection, includes observations such as the collapse of

certain fisheries in the Great Lakes, loss of potable water supply because of an epidemic such as the typhoid outbreaks that took place at the turn of the century, or the number of beach closures occurring over a certain period of time as happened on the Ottawa River. Although criteria information indicates a need for environmental management, it does not help make decisions to avoid such situations or identify solutions to ameliorate the problem; therefore, it is not relevant to this discussion.

General Monitoring

To determine the state of the aquatic resource requires a general monitoring program that will yield data describing the presence, level, and change over time of specific chemicals entering the aquatic system as a result of man's activities. Such programs include the collection of water samples at regular intervals and usually over the course of a number of years. Data generated from these collections are used to describe an average water quality condition of the sites. An example of such a network has been the general water quality monitoring carried out by the Water Quality Branch of Environment Canada, which is based on fixed sampling sites and monthly sampling frequencies (Whitlow, 1985). Such a network emphasizes statistics to quantify the accuracy and precision of the baseline data generated (see Loftis et al. 1983; Sanders and Ward, 1978). When operated over a period of time, the program yields data suitable for long-term trend or intervention analyses.

Often, these data sets are also used to assess compliance with water quality objectives. Usually, these objectives are a simple concentration of a chemical in water, and the linking of the measurement and evaluation components of water quality management becomes little more than asking the perennial question, do ambient conditions comply with the objective? Because of our present reliance on fixed monitoring sites, considerable effort has been made to study the stochastic nature of general monitoring (Ward and Loftis, 1983) and determine the probability of exceeding a water quality objective or guideline at any particular point in time.

Compliance monitoring for water quality objectives in the Prairie Provinces is based on a two-level approach that provides a short- and long-term objective for each water quality variable of concern. The short-term objective is most commonly based on laboratory-derived criteria, whereas the long-term objective is developed from system variability (historic mean concentration ± 2 Standard Deviations) to account for seasonal variations. Considering the episodic nature of diffuse source loadings, the long-term objective is more relevant for water quality management concerned with diffuse source inputs. For example, the use of herbicides and pesticides in the Prairie Provinces follows crop cycles; application and land runoff provide event-oriented inputs to the aquatic ecosystem. General water quality monitoring in the area has demonstrated the presence and levels of pesticides throughout the area and indicated some presence of lindane and alpha-BHC in locations well beyond the areas of use (Gummer, 1978). Although such a data set indicates the need for water quality objectives, it does not provide the information to site-adapt the objectives with respect to potential effects within the system.

Process Assessments

Designing environmental monitoring or assessment to provide scientific advice for a specific issue requires a third type of assessment—monitoring to characterize the behavior of the system. Specific questions must be addressed. Is the correct substrate being sampled? Is the hydrological regime of the system being taken into account? Are seasonal variations in concentrations and loadings being considered? These exemplify the need for a comprehensive multi-media approach to characterizing a system, if effective water quality objectives are to be developed and used to provide advice for sound water quality management. This requires a knowledge of the natural processes that regulate and often determine environmental quality within an aquatic system.

Environmental priorities such as acid rain or toxic substances make it critical to know both the environmental exposure and ecological effect of toxic chemicals. Exposure is a function of partitioning a chemical among the media under consideration (see Chapman et al. 1982); whereas, the effect is a function of the system's tolerance to the imposed stress. The need for process assessments was emphasized by Chapman et al. (1982). They concluded that a full understanding of the behavior of priority pollutants in the aquatic environment will require collecting considerably more information than chemical concentration in certain compartments.

By virtue of its diffuse nature, understanding of nonpoint source pollution relies more on monitoring and assessment than does point source pollution. Direct measurement of diffuse pollution sources is very difficult if not impossible; thus evaluation (using water quality objectives) depends upon a more careful monitoring of the system. General monitoring is often satisfactory for point source pollution because what and how much has been contributed to the system is known. However, without the benefit of accurate information on pollution inputs, more comprehensive monitoring is needed to evaluate nonpoint source pollution.

Process assessment requires measuring the system's variability and examining the physical–chemical and biological processes that determine environmental quality. Variability should consider statistical estimates of variance as well as include the comparison and analysis of the different sets of physical–chemical conditions. Understanding system behavior is an essential component of environmental management, and criteria, guidelines, or water quality objectives developed for good management practice must be adapted to system behavior. Process assessments provide the third step in developing relevant water quality objectives and implementing wise environmental management.

The value of process assessments is perhaps best described in the Great Lakes phosphorus management program. General monitoring provided estimates of total phosphorus loads within the lakes. From 1972 to the present, phosphorus loadings declined dramatically because of point source controls (1 mg/L), legislative controls (detergents), and nonpoint source controls (no till). To effectively manage phosphorus, and thus control the eutrophication of the Great Lakes, it was essential to determine what forms of phosphorus were most bioavailable and what sources should be emphasized for control programs.

Although it showed decreased loadings and concentration declines in Total Phosphorus, general monitoring could not provide the essential data to make such decisions. Process monitoring, such as bioassays of phosphorus availability and utilization, could distinguish the importance of the various sources. Consequently, appropriate decisions to target phosphorus loads for each of the lakes were made and agreement was reached on the most effective way to achieve the target levels.

During the 1960's, insecticides such as DDT and Dieldrin represented a major diffuse source input into Lake Michigan. Following the ban on the use and manufacture of these compounds in 1970, greater than 90 per-

cent declines of DDT levels were measured in bloater chubs between 1970 and 1980, and concentrations approached the Great Lakes Water Quality Agreement Objective of 1.0 μg/L. Dieldrin, however, increased in bloater chubs over this time period, and concentrations continue to remain over the water quality objective of 0.3 μg/L.

The different environmental behavior of these two compounds following regulatory action emphasizes the need for process information. When developing water quality objectives it is essential to know if a specific water quality objective is achievable and how long it might take to meet this objective. A lack of diffuse source input information makes it difficult to discern if further controls are required. What is the process that regulates levels of dieldrin in the environment, and why is it different from DDT? Process information is not yet available but is essential to answer such a question.

For the Great Lakes, water quality objectives supported by general monitoring have helped determine the need, type, and priority of remedial effort required. They provided an indication of the general health and response of the system. However, to maximize the effectiveness of water quality objectives, both in terms of their validity and especially their management potential, process information has been needed. Process assessments better resolve how to obtain the specific levels represented by the water quality objectives. They also evaluate the significance of nonpoint sources of pollution to encourage more efficient water quality management.

This point became apparent during the 1970's general monitoring programs in the Qu'Appelle River Basin of Saskatchewan which revealed that Province of Saskatchewan water quality objectives (which are not site-specific) for nutrients were routinely being exceeded. On the basis of this monitoring and evaluation, it was assumed that point source pollution was primarily responsible for this situation. Management adopted the position that controlling point source pollution would alleviate the problem. Tertiary waste treatment for the upstream cities of Regina and Moose Jaw was installed. Subsequent monitoring revealed little difference in nutrient values and it was not until detailed process assessments took place that a significant source of nutrients was determined to be of nonpoint origin. Present water quality objectives, which are not site-specific, have limited potential for water quality management because of the overall significance of nonpoint contribution of nutrients to the system. Therefore, process assessment in this case indicates that water quality objectives are probably not achievable through point source controls but require comprehensive nonpoint source mitigative measures.

CONCLUSIONS

Water quality monitoring for nonpoint source pollution must be taken into account for developing and maintaining water quality objectives. Evaluating the significance of this pollution (through water quality objectives) and formulating management responses rely on more dynamic assessments than those provided by general monitoring. In some situations general monitoring that relies on describing average condition may be the most cost-effective solution to supporting (as opposed to developing) water quality objectives. However, nonpoint source pollution more often demands a detailed characterization of a system's water quality. A knowledge of the processes and interrelationships that regulate environmental quality within any aquatic system is usually required.

With Great Lakes eutrophication, the system forgave the immediate lack of process information. However, present day priority issues such as acid rain and the entry of toxic substances into the environment will not be as forgiving. In the interests of protecting and sustaining Canadian water resources, studies emphasizing the knowledge of the system must be carried out. These data are essential in developing relevant water quality objectives and designing networks to support them. Furthermore, as the use of water quality objectives grows, the information gained from such studies will provide some interpretable data, both in terms of information on the system and in assessing the health of these resources.

ACKNOWLEDGEMENTS: The authors wish to thank William D. Gummer, Chief, Water Quality Branch, Environment Canada, Western and Northern Region, for his careful review and critical comments on this manuscript.

REFERENCES

Chapman, P.M., G.P. Romberg, and G.A. Vigers. 1982. Design of monitoring studies for priority pollutants. J Water Pollut. Control Fed. 54(2): 292–7.

Environment Canada. 1983. Annual Report 1982–83. Ottawa.

Gummer, W.D. 1978. Pesticide monitoring in the prairies of Western Canada. Water Qual. Inter. Rep. No. 4. Inland Waters Director., Environ. Can., Regina.

Loftis, J.C., R.C. Ward, and G.M. Smillie. 1983. Statistical models for water quality regulation. J. Water Poliut. Control Fed. 55(8): 1098–1104.

Sanders, T.G., and R.C. Ward. 1978. Relating stream standards to regulatory water quality monitoring practices. *In* Proc. Am. Water Resour. Assn. Symp. Establishment of Water Quality Monitoring Programs. San Francisco.

Ward, R.C., and J.C. Loftis. 1983. Incorporating the stochastic nature of water quality into management. J. Water Pollut. Control Fed. 55(4): 408–13.

Whitlow, S.H. 1985. Water quality assessment in Canada. Water Qual. Bull. 10(2): 75–9.